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B5G and 6G: Next Generation Wireless Communications Technologies Demand and Challenges

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***Abstract* — Fifth-Generation (5G) is being commercialized worldwide, while research institutions around the world have started to look Beyond 5G (b5G) and Sixth-Generation (6G) is expected to become the next generation of wireless communications technologies. The demand for wireless connectivity has grown exponentially over the last few decades, to meet the demands of future connectivity a significant improvement needs to be made in communications technologies. A new paradigm of wireless communication, the 6G system, with the full support of massive multiple inputs multiple-output (MIMO) system and millimeter-Wave (mmWave), is expected to be implemented between 2027 and 2030. B5G, some fundamental issues that need to be addressed are higher system capacity, higher data rate, lower latency, higher security, and improved quality of service (QoS) compared to the 5G system. This paper discusses the next generation of wireless communications technologies which is the future of 6G wireless communication and its network demands and challenges. Discussion on the mmWave and terahertz communications, as well as massive MIMO systems, are the main focus for the challenges of the technologies to meet the demands and user requirements. Besides, expected applications with 6G communication requirements and possible technologies are presented. The last part also describes potential challenges and research directions for achieving this goal.**

***Keywords*—Wireless Communication, Terahertz, MIMO System, B5G, 6G**

I. INTRODUCTION

The evolution of wireless communication technology started a few decades ago by introduced First Generation (1G) in the year 1980's for voice communication only with an analog system. Second Generation (2G) in the year 1990's used digital modulation technologies such as Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) as well as support for Short Message Service (SMS). Third Generation (3G) wireless communication which available in the year the 2000s has a major transformation with a high data rate that available for video communication (video call). In the year 2010's a Fourth Generation (4G) wireless technology introduced with the capability of high-speed data communication, not only video calling but be able to do a video conference with many peoples up to a few hundred of peoples [1][2]. Fifth Generation (5G) and Beyond 5G (B5G) are technologies that are currently being commercialized since the year 2020 some countries introduced 5G technology with the capability of transfer data up to Gigabits communication. Sixth Generation (6G) is a technology for the future with the target of data communication up to Terabits per second expected available in the year 2030. Refer to the evolution of wireless technology started from 1G to 6G mostly the sequence and transform to the new technology in every ten years [3][4].

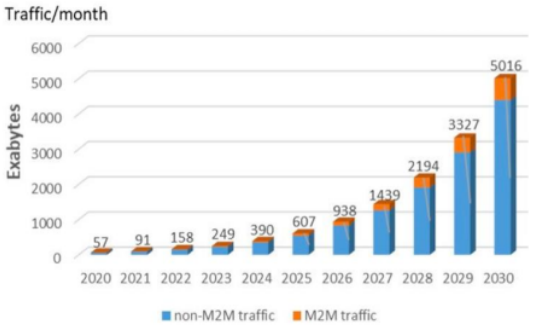

Fig. 1. Prediction of growth global data traffic in year 2020 to 2030.

The increasing number of devices connected to the internet very significant every year, the use of the internet is not only for communication but for other purposes such as data sharing, sensors, automation systems, etc. Furthermore, the introduction of Internet of Things (IoT) technology which used the internet as a medium for data collection, controlling, and automation systems is required high data rate and bandwidth. Fig. 1 shows a prediction of global mobile data traffic in the year 2020 to 2030 by the International Telecommunication Union (ITU) [5]. Exponential of increasing data divided by two categories which are non-Machine to Machine (non-M2M) and Machine to Machine

(M2M) communication. M2M support for automation system which implemented by many companies and industries to reduce human interference for example industrial robots, self-driving vehicles, answer machine, etc.

II. Demand of High-Speed Communications

The demand for high-speed internet access for communications is mandatory to handle the significantly increasing number of users and devices connected to the internet. Everyday new subscriber keeps going on and required high data communication, the internet access is not only for voice and data communication but for industrial application, for example, intelligent robot to control industrial process, automatic answer machine, self-driving vehicle, and many more application that required high data rate and low latency. Since the users of the internet as a communication system in a variety of devices and purpose as well as in any kind of applications, thus the number of subscriptions become huge of numbers. Sensing and controlling technology is one of the applications that required a high data rate because they required real-time communication, furthermore including surveillance cameras with audiovisual communication need high bandwidth to send the information. Table 1 shows detailed types of subscriptions in the year 2010 and 2020 and predicted to the year 2030 [6]. According to the prediction in the year 2030, the high of mobile subscription up to 17 billion devices with traffic volume up to 5016 Exabyte per month. The huge of data traffic for communication have to take attention and concrete solution before the date else the communication become down and jam that effected in many applications used [7].

TABLE I. Prediction of number subscriber in 2030

Issue	2010	2020	2030 (Predicted)	Unit
Mobile Subscriptions	5.32	10.7	17.1	Billion
Smartphone Subscriptions	0.645	1.3	5.0	Billion
M2M Subscriptions	0.213	7.0	97	Billion
Traffic Volume	7.462	62	5016	EB/month
M2M Traffic Volume	0.256	5.0	622	EB/month
Traffic per Subscriber	1.35	10.3	257.1	GB/month

Besides mobile communication, Machine to Machine (M2M) communication may take attention as well, because the subscription up to 97 billion devices with data traffic up to 622 exabyte may be affected to total traffic that required action and proper action plan, else the M2M used by industrial may get a problem and the use of technology in M2M automation get effected. Online teaching and learning is one of the systems required high data rate, as the current situation in pandemic Covid-19, most of the school and University implementing remote teaching from home using online media such as Zoom, Google meeting, Cisco Webex, etc. High data rate consumes by online teaching because of the number of students attending in the class, in normal class number of students up to 40 peoples, in some case might be more up to 100 peoples. Thus, good system and broadband data communication keep increase with low latency, to fulfill the requirement of the applications.

Another future that consumes high data rate communication and data retrieving is the application in medical and healthcare services. Equipment and remote monitoring of patients become common in healthcare centers to monitor patients due to safety issues for medical staff especially doctors and nurses. By using a remote system to minimize direct contact between patients to medical staff, thus the use of wireless communication and bandwidth is high to get real-time and live to monitor of patients. The most hospital used digital equipment's to monitoring patients then all the record and history of data can be recorded for analysis and future purpose as well as for faster analyze.

III. Millimeter-Wave and Terahertz Communications

Currently, most of the spectrum used for communication is below 6 GHz for example cellular communication, wireless fidelity (Wi-Fi), Bluetooth communication, etc. The lower band of the spectrum gives good communication service and less complicated in terms of hardware design and suitable for voice and data communication. Besides the front services spectrum, there is a backhaul communication system such as for point to point for base station and most of them used spectrum below 60 GHz, the high spectrum for backhaul because is not direct communication to use and required high data rate to support all the clients. Fig. 2 shows all the spectrum available and use by many applications, telecommunication system applicable up to 3 THz band [8].

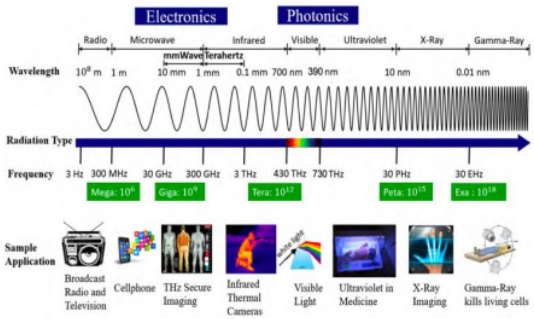

Fig. 2. All the spectrum bands available by many applications.

The use of high spectrum bands is required to handle crowded bands in lower spectrum, by the time increasing number of users and devices connected to the internet as well as spectrum requirements makes the system have to look for higher bands. Terahertz bands are one of the potential and possible spectrums for communication but there are some challenges use in these bands.

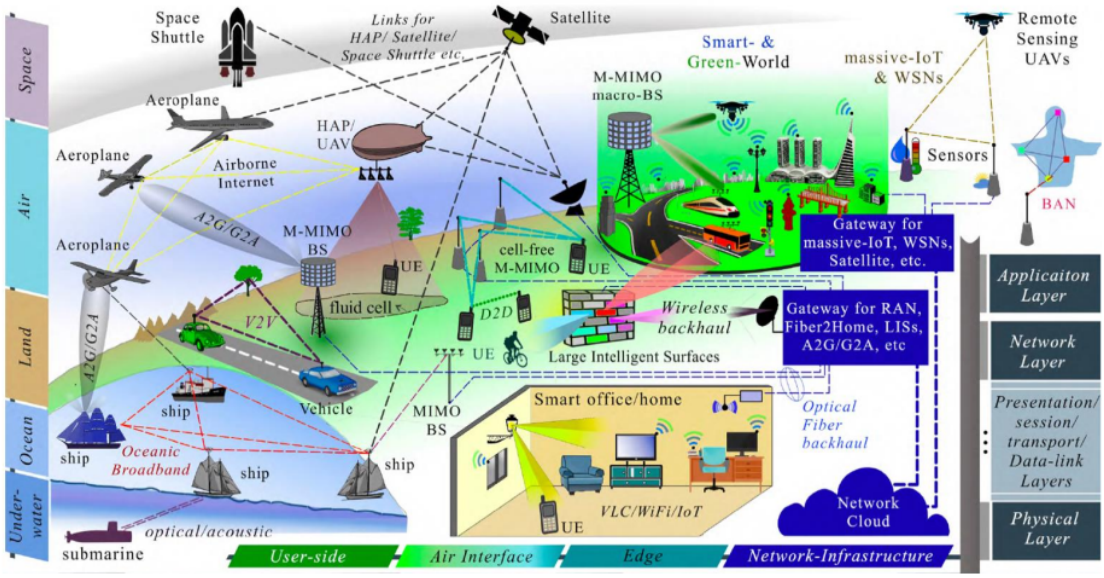

Fig. 3. Example of complex architecture of 6G wireless communications.

Today, communication systems only coverage for land and ocean to handle communications with most of them for voice and data used. The future communication system may very complex scenarios, everything's become connect to the internet and communicate each other's. Fig. 3 shows a complex scenario of wireless communication estimate in 6G technology [10]. Additional coverage areas such as underwater, air, and space are required since many devices have to connect to the internet for communication, sharing data, and other purposes. Thus, a wideband spectrum has to allocate in the future wireless communication system to facilitate the needed, as well as to cover all the number of devices. Furthermore, high-speed data communication has to prepare as well to tackle the huge number of devices connected with sharing data, and some of the devices required real-time communication with minimum latency for example autonomous vehicle communication. Fig. 4 shows terahertz bands with Millimeter Wave and hundreds of GHz slots [9].

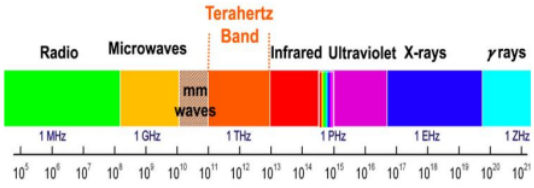

Fig. 4. THz band available with hundreds of GHz spectrum slots

Terahertz spectrum bands are one of the visible solutions to increase data rate and cover the huge number of devices, but there is a weakness of using a very high spectrum in the communication system, one of the limitations is the distance. The millimeter-wave (mmWave) bad into buildings penetration since in the urban area the buildings may in complex and blocked the signal. Reflected and attenuation of signal as well as inference to other devices may happen in a complex scenario in urban with a high number of populations. Path loss is another issue has to address to overcome bad in communication system but there is some solution for this issue such as increasing antenna gain and optimize the efficiency. Fig. 5 shows a graph of how the distance affected the path loss in frequency band microwave and mmWave from 0.1 to 0.35 THz [11][12]. The use of high spectrum bands with mmWave then penetration to obstacles during transmission is very susceptible to objects including raindrop when raining then the combination of the use of spectrum bands in a communication system is a possible solution to overcome the issue.

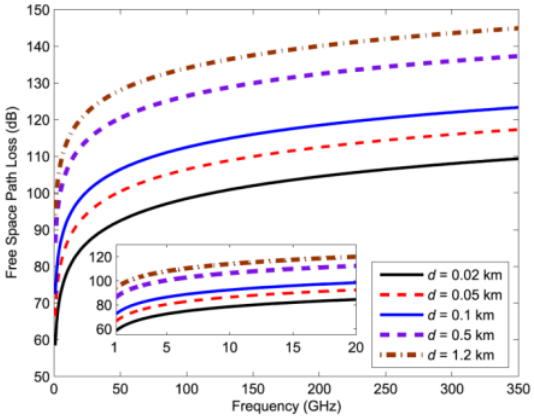

Fig. 5. Free space path loss in microwave and mmWave spectrum bands over different distances.

IV. Massive MIMO Communications

In the era of B5G and 6G communication system, a multi-input multi-output (MIMO) antenna system is a solution to increase the data rate, the requirement is very high up to Tbps then difficult to achieve by the current technology. The spectrum of radio in the lower band from 300 MHz to 6 GHz is already congested and not possible to get more channels for wireless communication then MIMO system is one of the solutions to increase the data rate. Classic massive MIMO has the capability to support in increasing data rate up to Gbps, while cell-free massive MIMO system expected to implement in 6G cellular communication to achieve Terabits data rate. Fig. 6 shows a massive MIMO comparison between classic and cell-free massive MIMO technology [9][13]. 6G of cellular communication expected to achieve a tremendous data rate in Terabits, thus cell-free technique has to apply by every device connected to contribute as a cell in the communication system. The use of higher spectrum bands assists in increasing data rate in the communication system but in some case very complex scenarios and environments make the system may not applicable [14][15].

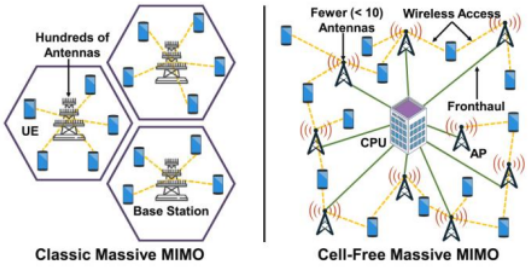

Fig. 6. Comparison of the classic and cell-free massive MIMO in cellular communication system.

To fulfill massive wireless communication then have to increase the performance of the system in term of Quality of Service (QoS), there are several solutions proposed and expected to overcome the low latency and high throughput as well as packet loss in QoS for next-generation B5G and 6G communication services. Explore and analyze the spectrum with low congestion frequency bands is another potential solution to increase the capacity that can find besides other proposed solutions. Fig. 7 shows a key enable for the next generation communication system which 6G and beyond to cover the requirements in the wireless communication system, cell-free massive MIMO, and Terahertz Band are the solution offered in this system.

Cell-free massive MIMO has a significant contribution to increasing the data rate and capacity because of the large number of individual antennas controlled by each device connected to the system. Distributed in wide of the area in simultaneous service in almost all the time which contribute by equipment's (UEs). This proposed method is a promising solution for the next-generation technology in wireless communication because of the ability to gives similar QoS to all UEs [16][17].

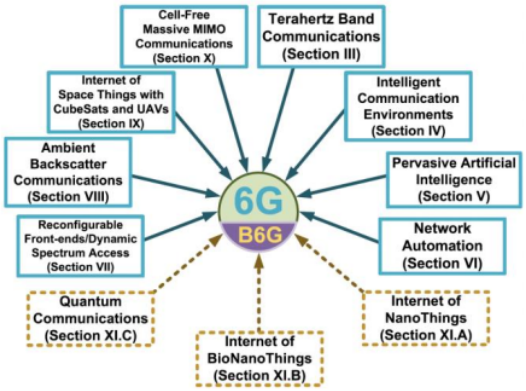

Fig.7. The envisioned key enabling technologies for 6G and beyond wireless communications systems [9].

In comparison to the traditional cellular system used a massive MIMO network to the proposed cell-free massive MIMO is the scheme gives high macro-diversity and has the capability to suppress the interference in multi-user. The actual deployment with a high probability that UEs is in large number to service as well as become access points then have to provide good channel condition. Table 2 shows in the detail of specific advantages and disadvantages of the massive MIMO system between, centralized, network, and cell-free [14][18].

TABLE II. Comparison Between Centralized Massive MIMO, Network MIMO, and CF Massive MIMO.

Architecture	Centralized	Network	Cell-Free
Number of antennas	large	moderate	large
Deployment cost	high	high	low
Macro diversity	small	moderate	large
Channel hardening	strong	weak	moderate
Favorable propagation	strong	weak	moderate
Uniform coverage	bad	moderate	good
Energy efficiency	large	small	very large
Channel estimation	global	global	local
Fronthaul resource	small	large	moderate

Furthermore, compared to the traditional massive MIMO system, cell-free massive MIMO networks expected can give significant features and outstanding performance compared to current massive MIMO technology which are: [14][19].

- Large energy efficiency.
- Flexible and cost-efficient deployment.
- The channel hardening and the favorable propagation conditions.
- Appealingly uniform quality of service.

V. B5G AND 6G KEY TECHNOLOGIES CHALLENGING

The deployment and commercialization of 5G technology in some countries started the last year 2020 shows that the evolution of wireless communication going forward, anyhow the performance and 5G system may no longer due to rapid increasing of user and high-speed data rate requirement. Thus, B5G and 6G technology have to do in advance before the commercialize date of 6G technology is coming. Although the current technology approach has indicated that 5G vision and performance in the right direction to achieve expected data rate and the high number of users. Many types of research are doing by the academician and research institutions worldwide to do similar objective and target in mobile or cellular communication. The objectives to achieve 1000 times faster and improvement compared to the current technology have to wait several years before the actual technology deploy and can be used. Table 3 shows a comparison of cellular technology in few years before which are fourth-generation (4G), fifth-generation (5G), and 6G technologies [9]. The 6G system implement in most of the issues with expect to achieve a super-fast data rate in Terabits per second. Support by artificial intelligence and extended reality technologies makes 6G technology promising in the future.

TABLE III. COMPARISON OF 4G, 5G, AND 6G KEY PERFORMANCE

Issue	4G	5G	6G
Per device peak data rate	1 Gbps	10 Gbps	1 Tbps
End to end (E2E) latency	100 ms	10 ms	1 ms
Maximum sprectral efficiency	15 bps/Hz	30 bps/Hz	100 bps/Hz
Mobility support	Up to 350 km/hr	Up to 500 km/hr	Up to 1000 km/hr
Satellite integration	No	No	Fully
Artificial Intelligence (AI)	No	Partial	Fully
Autonomous vehicle	No	Partial	Fully
Extended Reality (XR)	No	Partial	Fully
Haptic Communication	No	Partial	Fully
THz Communication	No	Very limited	Widely
Service level	Video	VR, AR	Tactile
Architecture	MIMO	Massive MIMO	Intelligent surface
Maximum Frequency	6 GHz	90 GHz	10 THz

The technology challenges to achieve a super high data rate up to Terabits as the target in B5G and 6G technologies are the complexity of the user scenario and have to manage and provide super high-speed data rate because of the increasingly huge number of new users (subscriber) to the internet system. Besides that the new user is not only for mobile devices but for machine and automation equipment's in industrial [20]. All these constraints and challenges have some potential solutions proposed by the researcher based on experiment have been done. The two solutions give high attention is introducing cell-free massive MIMO system and looking for higher frequency bands for communications system such as Terahertz band. Fig. 8 shows an example of a model cell-free massive MIMO system with several number user devices as front services then some number of devices as backhaul link to backend system [21].

The future wireless technologies are not only for communication, data sharing, automaton system, etc. but have the objective to address social issues by the next decade in the year 2030 as 6G technology expected to deploy and commercialize. Besides that, sensing system for the automation and data collection is another significant required bandwidth as well as demand for high data rate for transferring data in real-time. A large number of sensors connected to the internet and predicted by 2030 the number of sensors connected to the internet increasing to 700% compare by the year 2020 is 50 billion sensors [22]. The huge number of sensors supported by the IoT technology makes everything connected to the internet. Total data sharing from all the devices connected to the internet is predicted by 2020 up to 5016 Exabytes including machine to machine communication. Thus, the huge data have to handle by a super-fast communication system to avoid traffic congestion and delay.

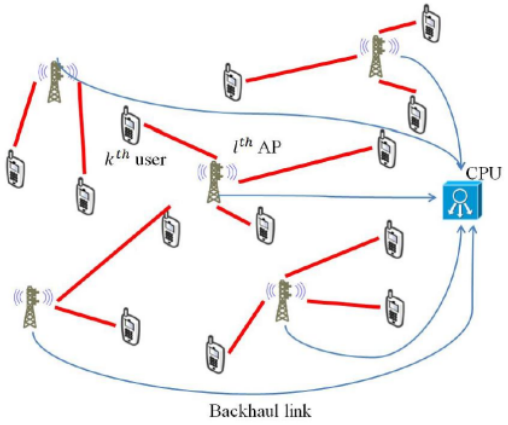

Fig.8. Example of model a cell-free massive MIMO system [19].

There are several trends to the upcoming decade in the use of data for communication and automation system, such as:

- Significant increasing wireless connectivity and use of mobile data.
- The use of mobile data for many applications including teaching and learning as well as automation in the industrial.
- The 6G communication system is one of the possible ways of technology.
- 6G technology service requirements for communication.
- Emerging 6G to other potential technology to fulfill the high data rate requirement.
- Expected 6G applications with the requirements of the QoS system.
- Possible solutions in challenges and research directions to reach the 6G goal.

VI. Conclusion

This paper evaluates the potential solution for future wireless communication especially for the B5G and 6G technology. These technologies are promising to support the requirement and demand of super high data rate and fulfill QoS wireless communication system. The significant increasing number of users dan the need for a high data rate makes the system have to explore new spectrum in higher bands that never use before to avoid spectrum congestion and interference. The use of higher spectrum bands especially in the Terahertz band may have challenges in a hardware design that need to do carefully to avoid caused to human or other systems. Cell-free massive MIMO system is one of the technology potentials to support communications system working at the physical layer. The challenges for the next-generation wireless system are to serve the huge number of devices and users connected to the internet with all the equipment's contribute the data and have to do in real-time with minimum delay or latency, especially in the automation system. Additional support for the next-generation system is introducing of artificial intelligence system in the wireless connection that makes the system smarter and more effective in determining the decision.

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